National Bureau of Standards

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# "Obstacle-Gain" VHF Transmission

RECENT EXPERIMENTS with long-range VHF transmission in mountainous regions have demonstrated the possibility of utilizing knife-edge obstacles as a means for increasing the received signal energy of television, FM, and military communications. Analyses of the experimental data and interviews with scientists and engineers in the field were conducted jointly by the U. S. Army Signal Corps, the National Bureau of Standards, and the Radio Corporation of America. Indications are that the disadvantages previously attributed to the transmission of very high frequencies (30 to 100 Mc) among high mountain ridges can actually become powerful aids for reducing both transmission loss and tropospheric fading. The results of these *obstacle-gain* experiments may have a deciding influence on the future choice of sites for transmitting and booster station installations. For example, in a region of the country like Colorado, it may prove more advantageous to locate FM and TV stations at lower elevations a short distance out on the plains away from the mountains rather than on the foothills close to the very high mountains of the Continental Divide.

Prior to the experimental verification of the *obstacle-gain* theory, which predicts the possibility of tremendous power gains for VHF propagation over mountain obstacles, long-range communication installations were located so as to be in radio line-of-sight of each other. When possible, installations were made on the tops of mountains as a means of gaining a wider service range. The extended utilization of the very high frequencies has further intensified the quest for the best geographical site on which to establish transmitting equipment. However, the sites are often relatively inaccessible, making construction expensive. The *obstacle-gain* phenomenon appears to offer a solution to this problem.

Preliminary studies of *obstacle gain*—which may be defined as the ratio of the received signal power with an obstacle in the path to the power received without it—showed that a considerable increase in received signal strength should result when a large knife-edge obstacle is located at the midpoint of the transmission path (unpublished memorandum for record by H. V. Cottony, Lt. Col., Department of the Army, Office of the Chief Signal Officer, on leave from the National Bureau of Standards). Japanese scientists have made similar theoretical and experimental investigations, and their installations were observed by the joint investigating team. The group also visited engineers and scientists conducting experiments in Hawaii and Alaska. The laboratories included in the investigation were the Electrical Communication Laboratory (Japanese Ministry of Communications), the Radio Research Laboratories (Japanese Ministry of Postal Services), the Mutual Telephone Company of Hawaii, and the Civil Aeronautics Administration stations in Alaska.

The theory upon which *obstacle-gain* transmission is based was originally proposed by Schelleng, Burrows, and Ferrell (*Proc. IRE 21, 427, March 1933*). Their hypotheses, which were partially substantiated by some experimental work, stated that the transmission of very high frequencies over a knife-edge type obstacle should be considered as a four-ray combination of reflection, diffraction, and atmospheric refraction. Thus, if a transmitter and receiver are separated by a mountain, the radio waves would be received by means of the



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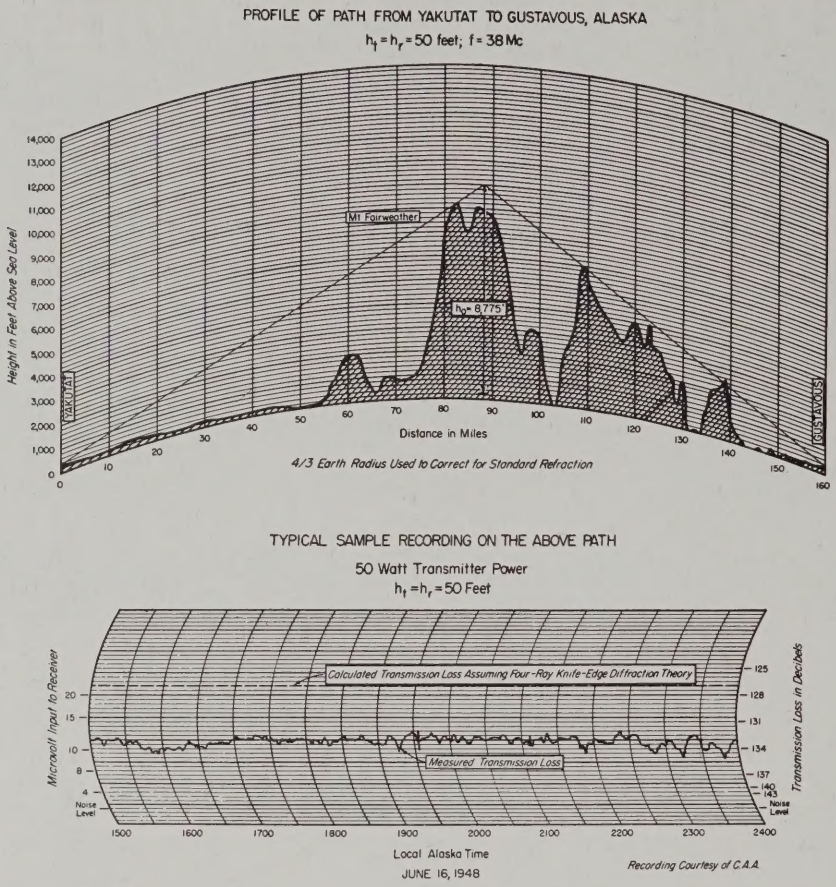

PROFILE OF PATH FROM YAKUTAT TO GUSTAVOUS, ALASKA
$h_t = h_r = 50$ feet; f = 38 Mc
Height in Feet Above Sea Level
Mt Fairweather
$h_0$ = 8,775'
YAKUTAT
GUSTAVOUS
Distance in Miles
4/3 Earth Radius Used to Correct for Standard Refraction
TYPICAL SAMPLE RECORDING ON THE ABOVE PATH
50 Watt Transmitter Power
$h_t = h_r = 50$ Feet
Microvolt Input to Receiver
Transmission Loss in Decibels
Calculated Transmission Loss Assuming Four-Ray Knife-Edge Diffraction Theory
Measured Transmission Loss
Noise Level
Local Alaska Time
JUNE 16, 1948
Recording Courtesy of C.A.A.

**That high mountain ridges may be used to increase the received signal strength of VHF transmissions has been demonstrated by an *obstacle-gain* experiment which utilized the knife-edge of Mount Fairweather (Alaska) as the obstacle (profile of VHF transmission path, top). A sample recording of the received signal (below) compares the transmission loss with that calculated from the four-ray knife-edge diffraction theory.**

following mechanisms: (1) Diffraction at the top of the obstacle; (2) reflection from the ground between the transmitter and the obstacle and then diffraction over the obstacle; (3) diffraction over the obstacle and reflection from the ground between the obstacle and the receiver; and (4) a combination of the two ground reflections with diffraction over the obstacle. The theory outlines methods by which the basic transmission loss over the path could be computed.

A requirement for the use of the *obstacle-gain* method for increasing signal strength is that the height of the obstruction must be greater than the elevation of the common horizon. For example, transmission losses will be considerably reduced at 100 Mc if a knife-edge type of obstacle for a 150-mile circuit is at the midpoint of the path and about 1,300 feet above the surrounding terrain. Theoretically, these conditions should result in a 30-db decrease in transmission loss over that which would be calculated if the obstacle were not there, with an accompanying increase in received signal strength (power gain of 1,000). The amount of reduction in transmission loss can be varied by different combinations of antenna heights, obstacle heights, and frequency.

One of the *obstacle-gain* experimental paths examined in detail was a 38-Mc, 160-mile communication circuit between Yakutat and Gustavous, Alaska, operated by the Civil Aeronautics Administration. The radio-wave transmissions, which originated from and terminated at low-level installations (approximately 200 feet above sea level), passed over a 9,000-foot ridge of Mount Fairweather. On the basis of the existing smooth-earth diffraction theory for an unobstructed path, the calculated transmission loss for the circuit is 207 db. However, on the basis of the four-ray theory and the assumption that Mount Fairweather acts as a single 8,775-foot knife edge, the expected transmission loss should be only 127 db. The experimental results showed the transmission loss was approximately 134 db, within 7 db of the value predicted by the knife-edge calculations. The transmission losses (127 and 134 db) correspond to a calculated obstacle gain of 80 db and a measured gain of 73 db, respectively, greater than the field strength normally expected when considering radio transmission over a smooth spherical earth. These experimental results constitute additional proof that a mountain can behave effectively as a knife edge.

Radio waves transmitted over the theoretical smooth spherical earth are considered to arrive at points within the radio horizon by virtue of a normal diffraction process and by scattering from the turbulent atmosphere. The turbulence, which is greater near the earth's surface and decreases with increasing height into the upper atmosphere, is also considered responsible for the relatively weak and fading signals nor-

mally observed at distances well beyond the horizon. (J. W. Herbstreit, K. A. Norton, P. L. Rice, and G. R. Schafer, Radiowave scattering in tropospheric propagation, *Institute of Radio Engineers 1953 Convention Record.*) The obstacle gains associated with a properly situated knife-edge ridge have been found to be large enough to reduce the transmission loss accompanying the reception of these signals beyond the horizon, thereby effectively eliminating the fading associated with the atmospheric scattering process.

A mountainous obstacle extending well above both the transmitting and receiving antennas requires the radio waves to pass through the most turbulent and disturbing regions of the atmosphere at relatively high grazing angles. With these large grazing angles, the amount of energy received from the highly turbulent regions in the screened lower portion of the atmosphere is effectively eliminated and so, in turn, is most of the tropospheric fading that normally exists on a nonobstructed path. One of the experiments designed to substantiate this theory was conducted over a 30-day period on the Alaskan circuit between Yakutat and Gustavous. The operating frequency was 38 Mc, and both the transmitting and receiving antennas were 50 feet high. During the recording period, the amount of energy delivered to the receiver was plotted against the time; the coordinates of the graph paper were also expressed in terms of transmission loss vs time. The instantaneous transmission loss for the period varied by less than $\pm 2$ db from a mean value of approximately 134 db. Furthermore, the measured transmission loss was only about 7 db greater than the loss calculated from the four-ray knife-edge diffraction theory.

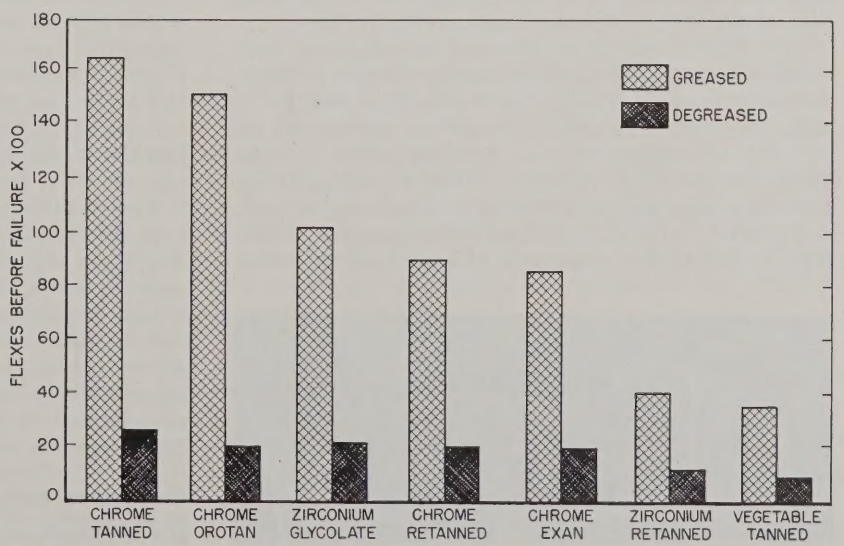
*For further technical details,* see Large reductions of VHF transmission loss and fading by the presence of a mountain obstacle in beyond-line-of-sight paths, *by F. H. Dickson (Office of the Chief Signal Officer, U. S. Army), J. J. Egli (Signal Corps Engineering Laboratories), J. W. Herbstreit (National Bureau of Standards), and G. S. Wickizer (RCA Laboratories), Proc. IRE* **41,** *No. 8, 967 (August 1953).*

# NBS Leather Flexer

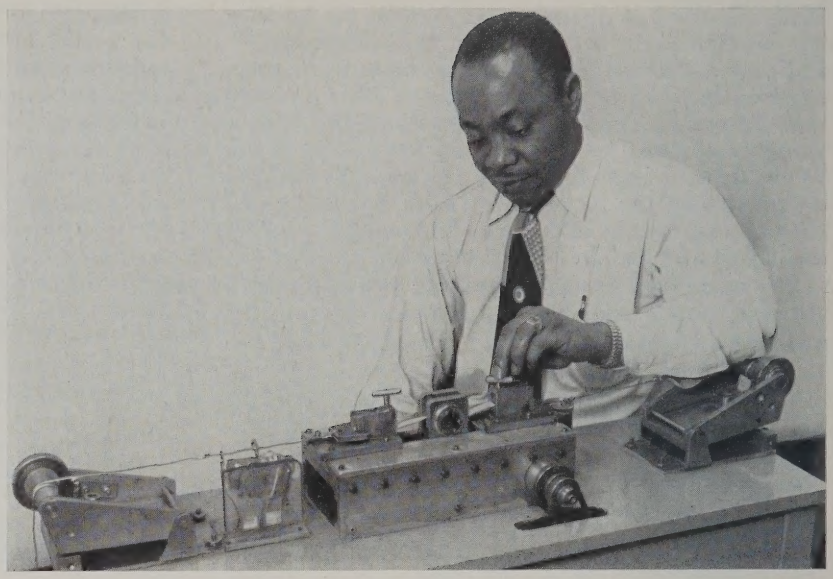
## A Flex-Tension Machine for Shoe Upper Leather

EXCELLENT FLEXING ENDURANCE has made leather especially suitable for the manufacture of shoes. However, satisfactory methods for measuring this property in leather have been lacking, largely because of the extremely long time required to cause failure of a specimen. Recently T. J. Carter and J. R. Kanagy of the NBS leather laboratory have developed a flex-tension machine which accurately evaluates the flex endurance of shoe upper leather within a relatively short time. The work was done in the course of an investigation of the flex life of leather sponsored at NBS by the Office of the Quartermaster General. The NBS leather flexer has proved effective in detecting differences in leathers due to tannage, lubrications, and other treatments. It should thus be of value in the development of improved leathers for shoe uppers.

The machine breaks down the leather by repeatedly bending a stressed specimen around two reciprocating rollers which stretch the specimen into an S-shape. The rollers are usually 3/16 inch in diameter and are mounted horizontally about 3/4 inch apart in a reciprocating assembly that produces double bends 120 times a minute. The specimen is held in place under practically constant tension by two movable jaws pulled in




**Flexing endurance of different tannages of shoe-upper leathers as determined by the NBS leather flexer.**



**In order to determine the flexing resistance of shoe-upper leather, the specimen is bent around two pins or rollers within the reciprocating assembly (center). Weighted cables over pulleys (right and left) keep the specimen under tension. The reciprocating action bends the specimen around the rollers, and flexing endurance is determined from the number of flexes before failure.**

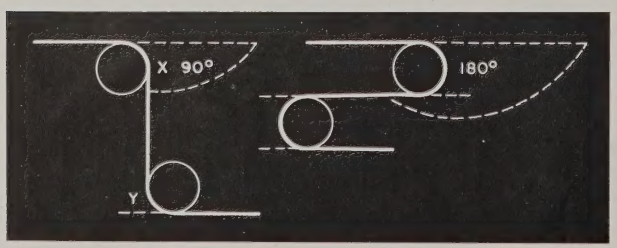
opposite directions by flexible wire cables to which hanging weights are attached. At each end of the machine the cable passes over a pulley provided with a ratchet to prevent backward movement of the jaws.

The reciprocating motion is in the direction of the applied tension. Thus, movement of the jaws outward from their initial positions during the flexing gives a direct measure of the stretch of the specimen. The axial loads must of course be equal so that there will be no tendency for the specimen to slip toward either side. Ordinarily the machine employs a 15-pound axial load, and the maximum displacement for each jaw is about 1⅝ inches.

The two rollers pass over about 2 inches of the leather specimen. As they are mounted on ball bearings, they can rotate freely over the leather without developing excessive frictional heat during the flexing. The roller assembly which fits into the flexing head can be rotated so that the angle at which the leather is bent can be varied, and the assembly is so designed that rollers having different diameters can be used.

The NBS investigation included the effects of load, roller diameters, specimen lubrication, angle of bend, temperature, and tannage on the flexural fatigue of upper leather. The effect of load was determined by varying the weights hung on the wire cables over the range from 6 to 21 pounds. Results indicated that flex life is inversely proportional to the change in load.

To determine the influence of roller diameter on flex life, the size of the rollers over which the specimen was bent was varied from 3/32 to 7/32 inch. Flexing time increased with the size of the rollers. When the number of flexes before failure was plotted against the diameter in inches, an essentially straight-line relationship was obtained.




**The leather specimen is bent around reciprocating rollers in the flexer. A 180° angle of bend is ordinarily used, but the endurance at 90° is approximately the same.**

The effect of bending angle was studied by changing the position of the rollers relative to the specimen. This was done by rotating the flexing assembly in either of two directions. The flexing endurance was greatest when the specimen was bent through an angle of 45°. At angles of 90°, 135°, and 180° there was no appreciable change in flexing endurance.

The studies also showed that flexural fatigue of leather is influenced by such factors as lubrication, temperature, and tannage, as well as direction of cut. Specimens cut in strips of ½ inch by 8 inches were used. Those cut in a direction parallel to the backbone line flexed longer before failure and stretched less than those cut in the perpendicular direction.

Specimens of commercial leathers were degreased with a solvent and then retreated with greases of various types and concentrations. The resulting differences in observed flex life clearly indicated the necessity for proper lubrication in leather where high flexing endurance is important. In general, it was found that the flexing time for degreased specimens was considerably less than that for greased specimens.

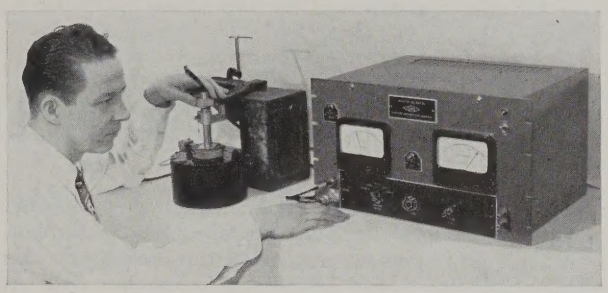
The effect of temperature on flexing endurance was evaluated by testing specimens at various temperatures. The result showed that the higher the temperature, the more rapid was the breakdown under flexure. A plot of the logarithm of the number of flexes to failure against the reciprocal of the absolute temperature gave an approximately straight line, from whose slope an apparent heat of activation for flexural fatigue was calculated. The highest heat of activation was obtained with chrome-retanned leather, but there was no

appreciable difference between the heat of activation for chrome-tanned, vegetable-tanned, and vegetable-retanned leather.

In studies of upper leathers containing different types of tannages, it was found that plain chrome-tanned leather flexed longer than the others tested. Vegetable-tanned leather showed the lowest flex life while the chrome-syntan, chrome-retanned, and syntans were intermediate in resistance to flexing.

*For further technical details, see* A flex-tension test for leather, *by T. J. Carter and J. R. Kanagy, J. Am. Leather Chemists Association (in press).*

# *Vibration Pickup Calibrator*



**An instrument for the calibration of vibration pickups and accelerometers operates on the principle of the mutual inductance transducer. The transducer probe (left center) is mounted on a massive block to reduce ambient vibrations.**

AN INSTRUMENT that calibrates vibration pickups and accelerometers rapidly and reliably has recently been devised by W. A. Yates and M. Davidson of the NBS electronic instrumentation laboratory at the request of the Navy Bureau of Ships. The device operates on the principle of the mutual inductance transducer, which was originally developed by the Bureau to measure small displacements and has since been applied in a number of NBS measurement instruments. The instrument has an accuracy of 5 percent over wide frequency and amplitude ranges, and can easily be standardized by using a calibrated displacement such as that provided by a precision dial gage.

In recent years the widespread use of vibration pickups for simultaneously monitoring a large number of points has introduced a serious calibration problem. Analysis of the problem has been complicated by the higher frequency components of vibration and resonant properties of the pickups. The increase in the number of pickups has emphasized the need for a rapid, reliable means of calibration over wide ranges of frequency and amplitude. Many of the calibration techniques now in use are limited in bandwidth and are difficult to standardize. Others require tedious point-by-point measurement and involve a considerable problem in data reduction. The NBS instrument was designed to overcome these deficiencies.

The vibration sensing element of the NBS instrument is a stable noncontacting displacement transducer of mutual-inductance type, developed by M. L. Greenough of the NBS staff for use in other instruments (*Electronics 20, No. 11, 172, November 1947*). The transducer utilizes the principle that the field surrounding a coil energized with alternating current will induce current in a nearby coil. The amount of current thus induced can be controlled by placing a conducting shield at various distances from the latter coil. In the Bureau's calibrator, vibration of a nonmagnetic conductive surface with respect to a probe containing the two coils and a carrier detector for the secondary winding generates an a-c component of output voltage proportional to the amplitude of vibration. In the normal use of the instrument, this a-c component is measured by means of a stable vacuum-tube voltmeter, producing a reading proportional to the amplitude of vibration. It will respond to frequencies from 10 to 20,000 cps and amplitudes from 10 microinches to 0.01 inch. This is an acceleration range of $2\times10^{-4}g$ to $4\times10^{5}g$.

The instrument is standardized by chopping the detected d-c voltage increment produced by a standard mechanically measured displacement change, in this case 0.02 inch, into a square wave. Fed into the same a-c peak-to-peak voltmeter on the 0.01-inch range, the square wave is equivalent to a 0.01-inch peak amplitude of vibration. The sensitivity of the voltmeter is then adjusted to obtain a full-scale reading. The choice of a displacement as an absolute standard for the instrument was made primarily because of the ease with which it can be reproduced without special equipment.

The use of a displacement transducer in this application presents both advantages and problems. The principal difficulty encountered is that of mounting the probe, since the mount itself must be free of ambient vibrations if the full capabilities of the instrument are to be realized. This requirement is met by using sturdy, rigid brackets. An advantage of this type of transducer is that it introduces practically no loading on the vibration generator. Thus, the generator can be designed solely on the basis of the loading imposed by the pickups to be calibrated, and significant savings can be achieved in equipment for high-frequency calibration.

The engineered instrument consists of the transducer in the form of a probe and an encased chassis which contains the electronic circuitry and to which the probe is attached by means of a cable. Direct meter indications of the peak amplitudes of sinusoidal vibrations are given. The operation of the instrument requires that the probe be mounted at a fixed distance from the mean position of the vibrating surface. For this pur-

pose a meter indication of the probe-to-surface spacing is provided, enabling the operator to make the necessary settings quickly. This adjustment is not nearly as critical as the adjustment required by capacitive types of vibration transducers.

*For further technical details, see* Wide-range calibrator for vibration pickups, *by W. A. Yates and M. Davidson, Electronics,* **26,** *No. 9, 183 (September 1953).*

*For other applications of the NBS mutual inductance transducer, see* Electronic micrometer, *NBS Technical News Bulletin* **31,** *37 (April 1947);* Micromanometer, *NBS Technical News Bulletin* **34,** *137 (October 1950);* Oil film thickness indicator, *NBS Technical News Bulletin* **35,** *120 (August 1951);* Electronic sensing of mercury column height, *NBS Technical News Bulletin* **36,** *26 (February 1952).*

*For other vibration calibration work at NBS, see* Reciprocity calibration, *NBS Technical News Bulletin* **32,** *1 (January 1948);* Accelerometer calibrators, *NBS Technical News Bulletin* **32,** *142 (December 1948).*

# Iron-Constantan Thermocouple Tables

NEW REFERENCE TABLES for iron-constantan thermocouples, recently prepared by the Bureau, constitute an important step toward uniformity in this field. Covering a very broad range—from −310° to +1,600° F—the new tables correspond more closely to the properties of commercially available thermocouples than do any of the other iron-constantan reference tables currently in use. The NBS tables are based on an investigation carried out by R. J. Corruccini, Henry Shenker, and other members of the Bureau staff at the request of the Scientific Apparatus Makers of America. They have been recommended by the SAMA for adoption as a tentative standard.

Thermocouple reference tables are widely used in science and industry for determining temperatures from observed thermocouple voltages and in the preparation of purchase specifications for thermocouple wire. They are also used to define the relation between impressed emf and scale reading for pyrometers which indicate temperature directly. In practice, the calibration of an individual thermocouple is ordinarily given in terms of deviations from such a reference table. Because it is usually not convenient to change the scale of a direct-reading pyrometer to compensate for variations in the thermocouples which may be used with it, thermocouples are commonly purchased under specifications which ensure that they will correspond closely to the graduation of the particular model of pyrometer used.

For measurement of temperatures up to 1,500° F, the iron-constantan thermocouple is widely employed. Yet it is the only type of thermocouple for which uniformity of commercial practice has not yet been established in this country. Because such a small proportion of the total production of iron goes into thermocouples, pyrometer manufacturers find it more economical to select suitable lots from available commercial iron than to have iron prepared to specifications especially for thermocouples. As a result, a number of widely diverse reference tables have been used for iron-constantan thermocouples. Also, from time to time, changes in the composition of commercial iron being produced in this country have made these tables less representative of the iron thermocouples in actual use.

Various efforts have been made to achieve greater uniformity. In 1938 NBS derived a new table, known as the RP1080 table (*J. Research NBS 20, 337 (1938) RP1080*) which represented the average behavior of the commercially available iron-constantan thermocouples tested at that time. However, this table was not widely adopted, because its use in most cases would have involved changing the scales of the pyrometers then in use. Finally in 1948, the Scientific Apparatus Makers of America, representing several of the pyrometer manufacturers, adopted the temperature-emf relation known as the 1913 "L and N" table (this table, sometimes called the Leeds and Northrup table, is identical with the tables given in International Critical Tables *1,* 59 (1926) and in Tech. Pap. BS *14,* 306 (1920–21) T170, table IV, col. L) as a tentative standard for iron-constantan thermocouples over the range from 32° to 1,400° F. This relation was chosen because it was in wider use than any other. However, experience has shown that it has not been possible to produce a thermocouple from present-day commercial iron that will correspond precisely to the 1913 table. Moreover, any thermocouple that closely matches this table in the range below 1,400° F. has been found to deviate greatly from it in the range above 1,400° F. A further difficulty was the fact that the original 1913 table did not extend below 32° F. The SAMA therefore requested the National Bureau of Standards to derive a reference table that would be as close as possible to the 1913 table and yet be free from these defects.

Each member firm of the SAMA that supplies iron-constantan thermocouples was invited to submit sample thermocouples for investigation at NBS. These samples were to be of commercial materials selected to match closely the 1913 table over the range from 32° to 1,400° F. Eight different lots of matched iron and constantan wires of size approximately No. 8 AWG were submitted. Information received from some of the suppliers indicated that the iron samples came from at least four different basic sources of ingot iron.

The thermal emf's of the various wires were measured in the NBS temperature measurements laboratory from −319.5° to +1,800° F. From these data, the corresponding thermal emf's for the iron-constantan thermocouples were computed. Chemical and spectrographic analysis of the iron samples and hardness determinations were also made.

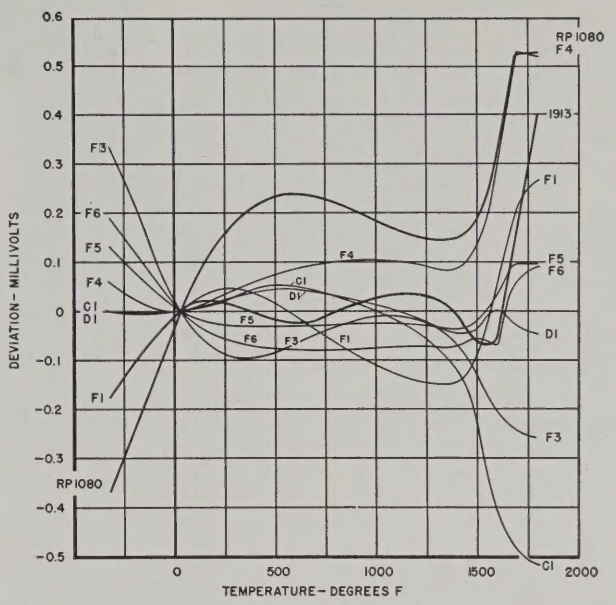
From 32° to 1,800° F, the wires were calibrated in a tubular electric furnace. For convenience, the iron wires were calibrated against a standard iron wire, and the constantan wires against a standard constantan wire. The standard iron and constantan wires had previously been calibrated against Pt 27, the NBS platinum thermoelectric standard, and they were rechecked at frequent intervals during each run against the platinum element of the platinum versus platinum-10-percent rhodium thermocouple used to measure the temperature. Because of the relative instability of the iron and constantan at temperatures above 1,400° F, measurements in this range were made against a platinum standard only.

From 32° to −319.5° F, the thermal emf of each wire against a copper reference wire was determined in stirred liquid baths. The copper reference wires were calibrated against a platinum standard. Down to −147° F, use was made of a special cryostat (*J. Research NBS 25, 459 (1940) RP1339*) developed at NBS which automatically maintains a constant temperature in a stirred liquid bath. Observations were made at two lower temperatures by use of baths of liquid oxygen and nitrogen stirred by a stream of the same gas. Temperatures in the baths were determined with a platinum-resistance thermometer.

Tables giving temperature-emf relations for the individual iron and constantan wires relative to the platinum standard at the various calibration temperatures were compiled. These data were then combined to give the corresponding relationships for the complete iron-constantan thermocouples.

As a result of the NBS investigation, the SAMA has recommended adoption of the temperature-emf relationship of one of the thermocouples studied, as a standard to replace the 1913 table. The temperature-emf relationship selected deviates least from the 1913 table in the range of normal use. The upper limit of the tentative standard has been set at 1,600° F because of the instability of iron-constantan thermocouples above this temperature and also because of the large increase in the deviation of the thermocouples studied by NBS from each other above this temperature.

In the course of the investigation, the Bureau invited suggestions from industry as to whether the new temperature-emf relationship would be acceptable as a standard (*NBS Technical News Bulletin 34, 174, December 1950*). The replies received were uniformly favorable to an industry-wide standard. Also, users and suppliers of thermocouples based on the 1913 table were consistently favorable to the adoption of the relationship obtained by NBS, which is similar to the 1913 table. However, most of the replies received from users and suppliers of solely RP1080-type thermocouples indicated that it would not be practicable for them to change to the proposed SAMA standard. Change from the RP1080-type thermocouples to thermocouples based on the new proposed standard would require alterations to most of the associated indicating equipment, whereas the difference between the 1913 and the new NBS-derived relationships is much smaller and is less than commercial tolerances for this thermocouple.



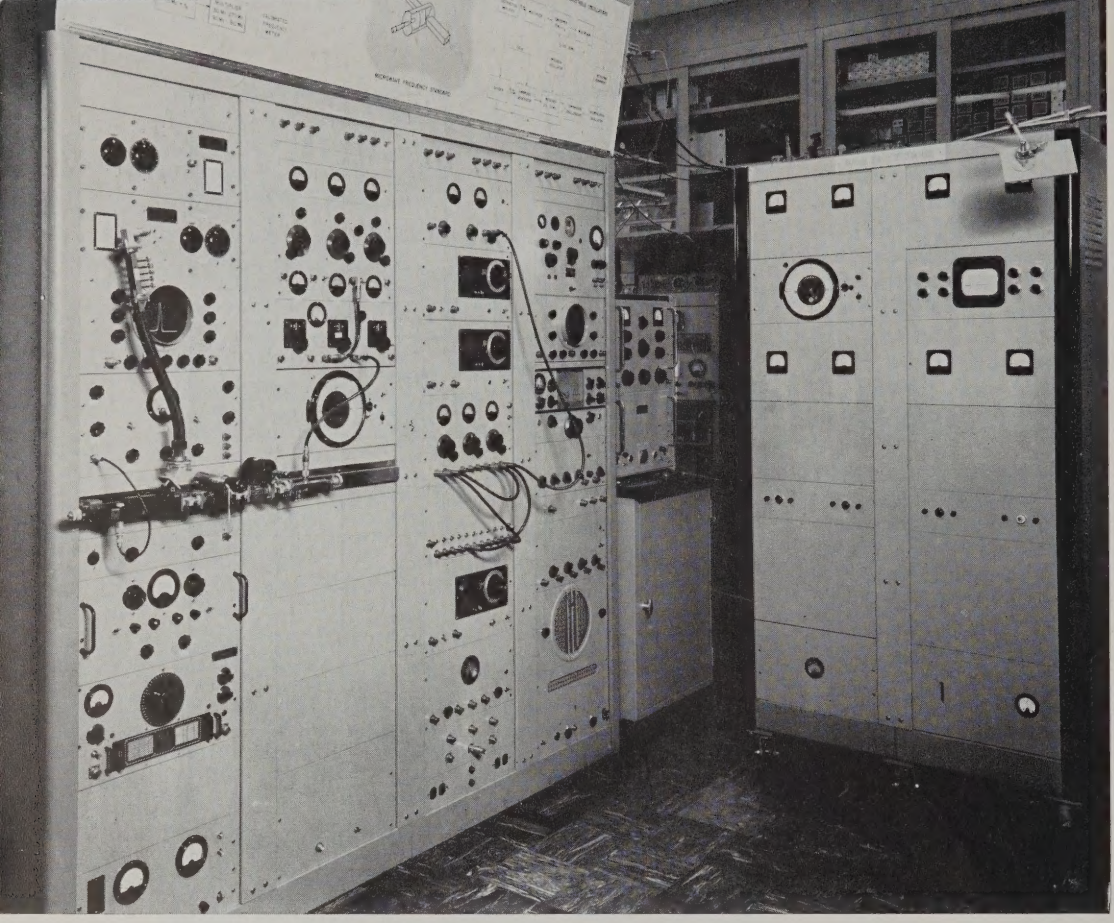

**Deviations of the 1913 table, the RP1080 table, and various iron-constantan thermocouples studied by NBS, from the temperature-emf relationship given in new reference tables for iron-constantan thermocouples.**

Thus it appears that at least two standards, the SAMA table and the RP1080 table, will coexist in the immediate future. Most commercial production of iron-constantan will probably be based on the SAMA table, as it has been based on the 1913 table in the past. On the other hand, one of the principal fields in which the RP1080 table is dominant—namely, piston-engined military aircraft—is declining in importance. Eventual adoption of an all-industry standard must of necessity depend upon the kinds of commercial iron that are available and the industrial uses to which iron-constantan thermocouples are to be put.

*Tables giving the new temperature-emf relationship for both Fahrenheit and Centigrade scales have been published by NBS. See* Modified 1913 reference tables for iron-constantan thermocouples, *by Robert J. Corruccini and Henry Shenker, J. Research NBS* **50,** *229, (1953) RP2415.*

## Mathematical Tables

*Simultaneous Linear Equations and the Determination of Eigenvalues,* National Bureau of Standards Applied Mathematics Series 29. This subject is of importance in many branches of pure and applied mathematics as well as in fields such as physics, chemistry and aerodynamics, where problems are most directly and naturally formulated as systems of linear equations. The approximate analysis of continuous problems like differential and integral equations leads to systems of linear equations and to the determination of eigenvalues of matrices. Order AMS29 from Government Printing Office, Washington 25, D. C.; $1.50.

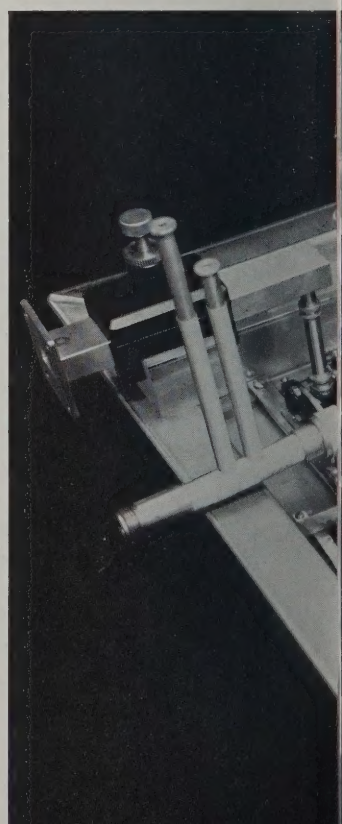


**Two transmission-type wavemeters (in front of relay racks, left) are mounted for calibration against the NBS microwave adjustable-frequency standard. The standard with its associated frequency multipliers, adjustable frequency oscillators, and metering and monitoring equipment occupy four racks (left). The system of panel jacks permits mixing many standard frequencies. The racks (right) house the electronic components of the Model II ammonia clock.**

# THE NBS MICR

IN AN EFFORT to keep pace with the growing utilization of an ever expanding radio frequency spectrum, the National Bureau of Standards maintains a program of research and development that is aimed to make available to science and industry accurate standards of frequency measurement. Research and development of frequency standards in the regions of the microwave frequency spectrum is the responsibility of the NBS Microwave Frequency Standards group under the direction of Dr. Harold Lyons and L. J. Rueger. The laboratory is equipped to operate between 300 and 40,000 Mc with completely standardized equipment (*NBS Technical News Bulletin 32, 12, December 1948*), and up to 75,000 Mc with instruments currently in the final stages of development. In addition to the broad research program in microwave principles and techniques, the laboratory calibrates the secondary microwave frequency standards used in science and industry.

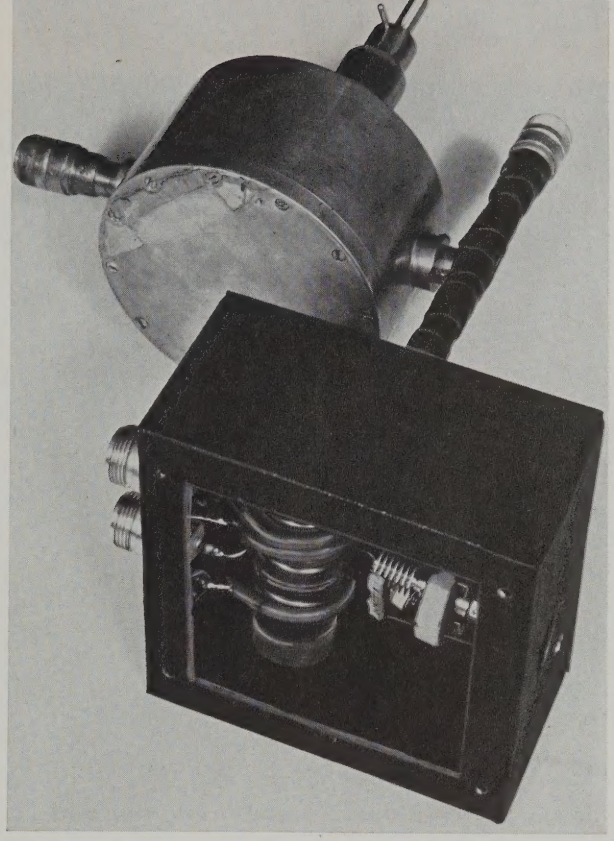
The vast spectrum of radio frequencies above 300 Mc is presently employed in such military applications as radar, navigation systems, blind bombing, and guided missiles. Research in microwaves has been responsible for better FM and television relay systems presently in operation and under construction. Microwave standards are equally important to medicine and to those industries utilizing electronic equipment, as in dielectric heating for case hardening of metals, rubber curing, plastic molding, food processing, textile fabrication, and radio-frequency therapy. Extended use of



**The klystron multipliers and amplifiers used in the microwave fixed-frequency standard are completely immersed in an oil bath which is gently agitated by a stirring motor and whose temperature is controlled to ±0.01° C. The outputs of the klystrons are fed into the calibrating system through matching sections of waveguide (left).**

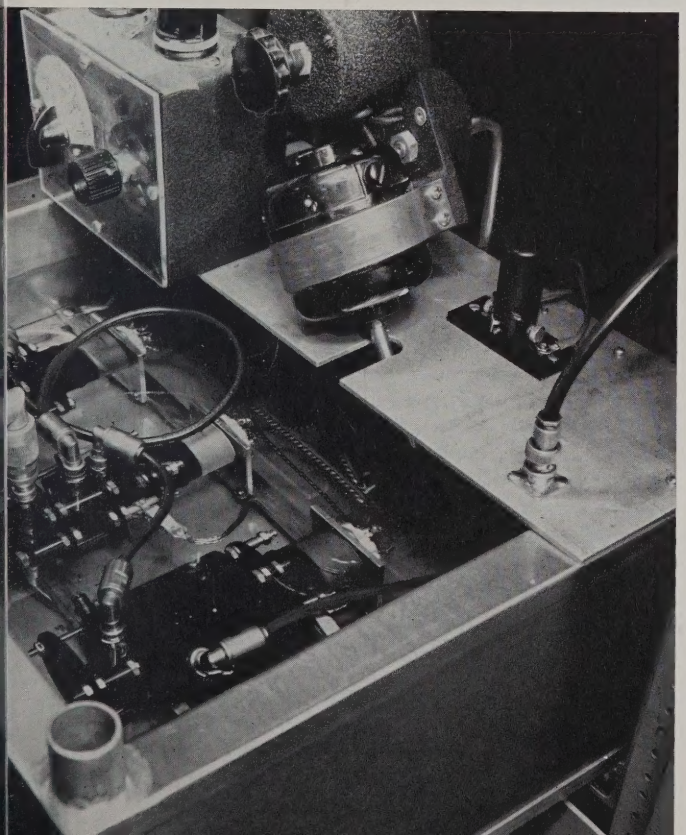
the millimeter bands (above 30,000 Mc) is important to work in microwave spectroscopy, microwave optics, and in applications requiring sharp microwave beams of high resolution, such as short-range target-seeking equipment for rockets and guided missiles. However, to exploit fully the far reaches of the microwave region it is necessary to have national standards and measurement methods which provide the necessary tools for the design, development, and production engineering of practical electronic equipment, and for basic research.

The microwave frequencies used by the National Bureau of Standards for calibration are derived directly from one of the stable 100-kc oscillators maintained by the Bureau for time and frequency standards. The frequency of the driving oscillator is determined to better than 1 part in 1 billion by reference to the other NBS standard oscillators and with astronomical observations made by the Naval Observatory. The standard oscillators also control the operating frequencies of the NBS radio broadcasting station WWV (Beltsville, Md.). Because the 100-kc signal must be multiplied up to thousands of megacycles, some difficulties arise because of noise and other small effects which tend to create a phase modulation of the frequency multiplier chain. In all, the frequency and phase modulation produced is less than 1 part in 100 million at 300 Mc, less than 1 part in 10 million at 24,000 Mc, and less than 1 part in 100,000 at 54,000 Mc. The increase in bandwidth at the highest frequency arises primarily as a result of the low signal strength of the generating equipment at these levels. In special set-ups bandwidths of less than 1 part in 10 billion have been achieved. By comparison, resonant cavities and other secondary frequency standards are rarely dependable to better than 1 part in 10,000, although some cavities have been constructed that will consistently function within 1 part in 100,000, but only if the temperature, humidity, and pressure are carefully controlled.



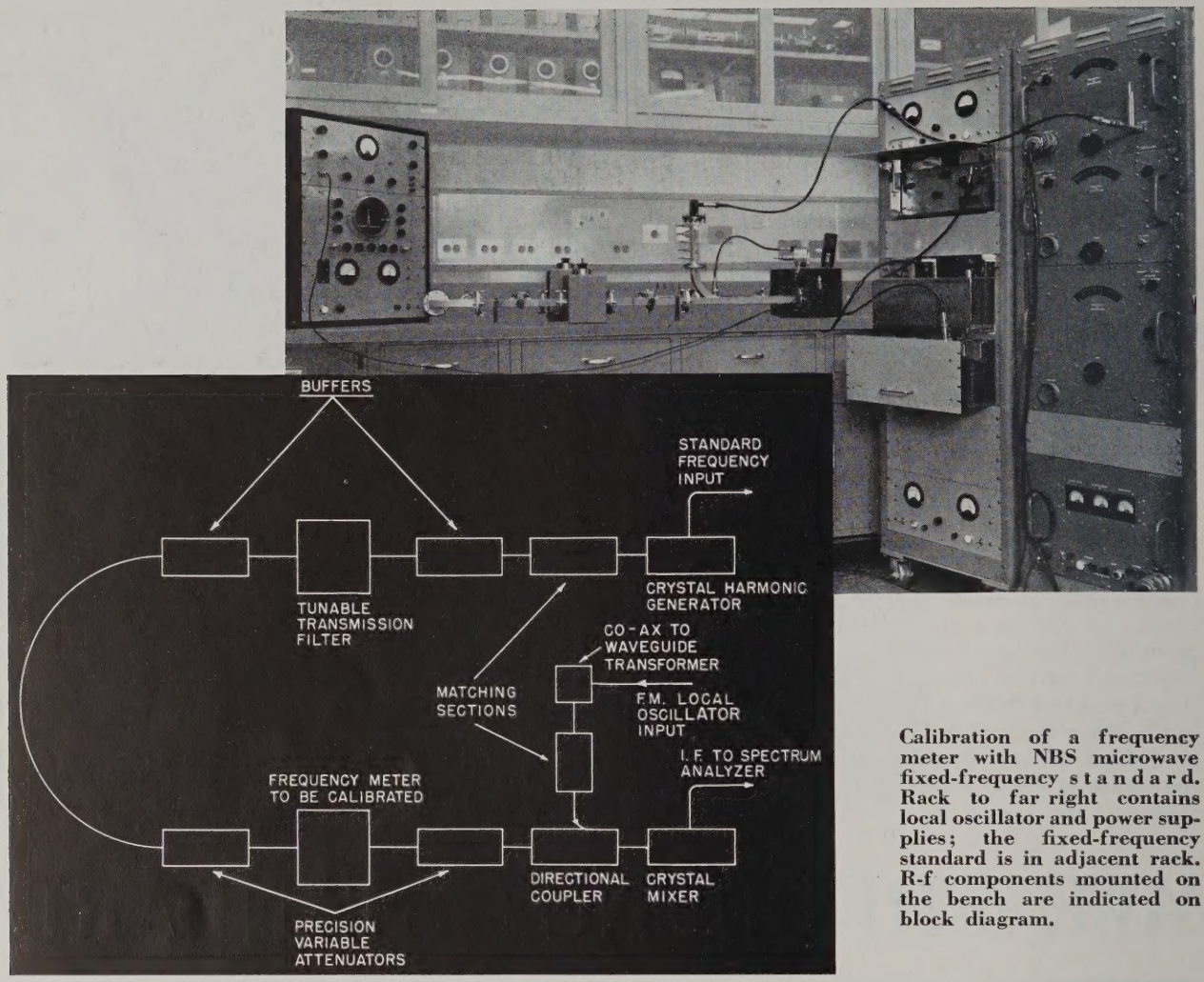
**Three standard signals (50 Mc and 250 Mc in small box, 3,000 Mc in cavity cylinder) are applied simultaneously to a crystal mixer for combining frequencies generated by the microwave fixed-frequency standard.**

# )WAVE FREQUENCY STANDARD



## Generation of Standard Microwave Frequency Signals

The 100-kc standard signals—from which the microwave frequencies are multiplied—are developed in a Meachan bridge oscillator circuit and a carefully, hand-tailored 100-kc crystal. They have a short-time stability (10 minutes) of 1 part in $10^{10}$ and a long-time stability (1 week) of 1 part in $10^{9}$. Two distinctly separate multiplier chains are employed in the NBS microwave frequency standard; one a fixed-frequency and the other an adjustable-frequency standard. In both systems, unwanted sidebands or harmonics are suppressed 60 db at each stage of the chain. Conventional grid-controlled vacuum tubes multiply the frequencies up to several hundred megacycles, while fixed-frequency klystron multipliers yield frequencies up to 25,000 Mc. Frequencies above this range are obtained




**Calibration of a frequency meter with NBS microwave fixed-frequency standard. Rack to far right contains local oscillator and power supplies; the fixed-frequency standard is in adjacent rack. R-f components mounted on the bench are indicated on block diagram.**

from crystal rectifiers employed as harmonic generators, the working frequencies of which are selected by a transmission cavity filter.

The NBS fixed-frequency standard has higher outputs than the variable system but is not as versatile. Frequency mixing is accomplished at the end of the chain (high-frequency mixing), the outputs of which permit a coverage of the spectrum at very closely spaced intervals. The strongest signals are obtained from the following mixing combinations: 10-Mc intervals through 5,000 Mc; 50-Mc intervals through 25,000 Mc; and 250-Mc intervals through 40,000 Mc. Errors in transcribing and plotting data are minimized because the signals occur at evenly spaced round numbers. Power outputs are: at the 10 and 50-Mc outputs, 5 watts; 250 and 3,000-Mc outputs, 1 watt; and 9,000-Mc output, 20 milliwatts. Power stability and long life are achieved in the klystron amplifiers and multipliers by immersing them in a temperature-controlled oil bath and operating them well below their maximum ratings.

Signals are generated in the adjustable-frequency standard by combining a fixed multiple of the 100-kc source with the signal from a precision oscillator continuously adjustable between 2 and 3 Mc. The combination frequency passes through tunable multipliers with a range of 10 percent. The adjustable range may be expanded to 100 percent by using the tenth harmonic of any output from the multiplier chain. Radio-frequency power available to the harmonic generators is at least 2 watts at each output of the multiplier chain. Excellent efficiency in the generator and the detector systems permits the use of harmonics as high as the 30th for calibration purposes and extends the range of the standard through 25,000 Mc. Frequency mixing is accomplished near the beginning (low-frequency mixing) of the multiplier chain, which has the advantage of wide separation between adjacent harmonics. A major disadvantage of the system lies in the fact that the very low difference intermodulation frequencies are multiplied in the chain together with the desired signal and consequently create unwanted sidebands.

When relatively high standard-frequency power (about one milliwatt) is required, a frequency transfer process can be used with the normal loss of overall

precision. Here, CW klystron oscillators are synchronized to a standard oscillator, and frequency modulation of the oscillators is minimized by using battery power and by stabilizing the klystron temperature in a temperature-controlled oil bath.

In those locations that are isolated from direct connection to the NBS standard oscillators, calibration of secondary frequency standards is possible by using one of the standard frequencies broadcast by radio station WWV (2.5, 5, 10, 15, 20, and 25 Mc) as a reference for synchronizing harmonics of an auxiliary 100-kc oscillator. Precisions of about 1 part in $10^7$ are attainable if reception is limited to sky wave propagation, or 1 part in $10^8$ if ground wave reception is possible. The National Bureau of Standards' ammonia clock (*NBS Technical News Bulletin 33, 2, February 1949*) has been used as a reference for absolute calibration to 1 part in $10^7$, and to a relative frequency constancy of 2 parts in $10^8$.

## Calibration of Secondary Standards

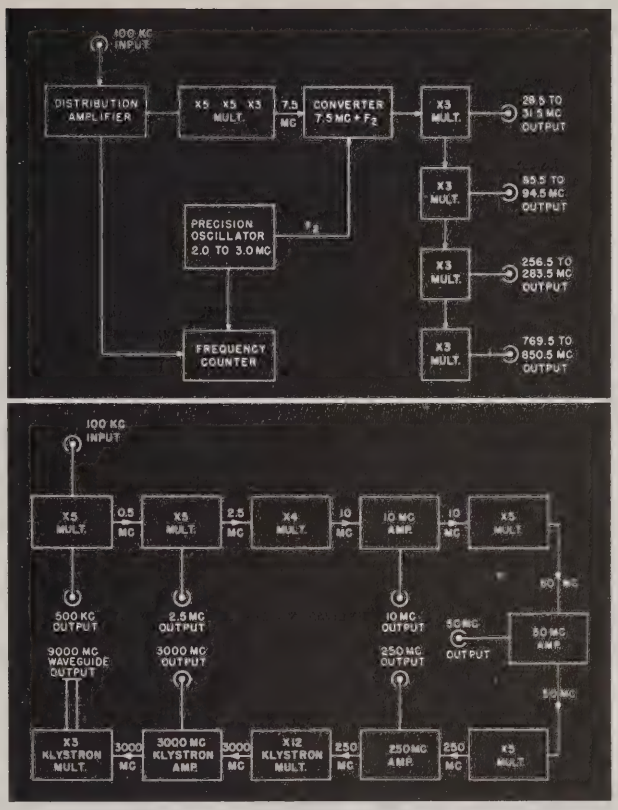
Frequency meters sent to the Bureau are calibrated, when possible, under normal operating conditions. For instance, if the meter has a built-in detector and indicator, sufficient power is used to operate the complete indicating system. Or, if the meter can be employed either as a tranmission or a reaction device, the calibration includes both methods, and checks are made for any existing discrepancies between the two. The ambient room temperature of the calibration laboratory is maintained at 23° ±2° C., and the relative humidity at 50 percent ±2 percent. Meters are permitted to reach equilibrium with the room conditions before a calibration is made.

In the calibration procedure, the standard frequencies are applied to a crystal diode mixer, a nonlinear device that generates all of the sum and difference combinations of the signal present. The desired signal is selected and all others are rejected by a tunable transmission filter, which has been previously calibrated. The output of a frequency modulated local oscillator is admitted to the converter crystal through a directional coupler, where it is mixed with the standard signal.

The intermediate frequency from the converter is fed to a spectrum analyzer and the matching sections are adjusted for maximum signal strength. Attenuators placed on either side of the meter to be calibrated are set at 10 db each, which effectively isolates the calibrating equipment and prevents reactive "pulling" of the meter.

The frequency meter to be calibrated is set to resonance at each calibration frequency at least ten times. The divergence or spread of the readings at a given frequency is then a measure of the backlash or other mechanical defects of the drive and indicating mechanism. This spread is included in the calibration report as the tolerance to which the readings are reproducible.

Although not included in a normal calibration, it is possible to measure the cavity-temperature coefficient of frequency near room temperature and the approxi-

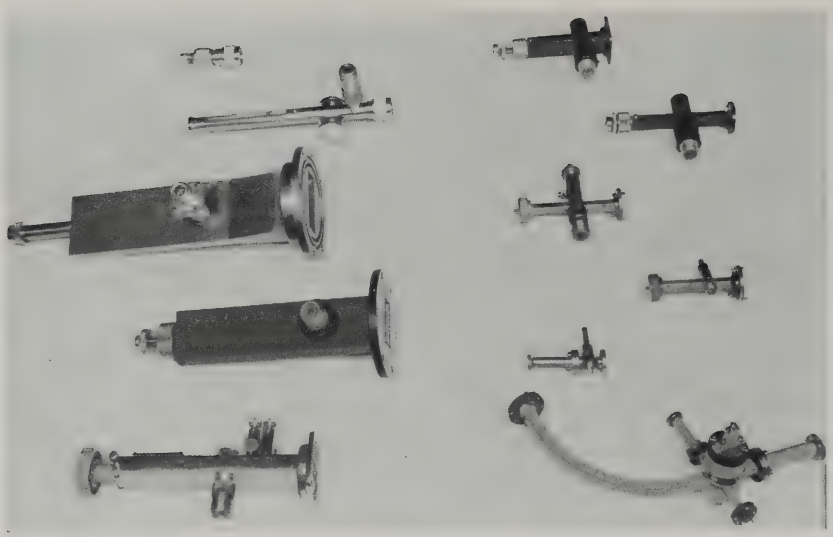



**Block diagrams of the microwave adjustable-frequency standard (above) and of the microwave fixed-frequency standard maintained by the Bureau (below).**

mate "$Q$" of the cavity. The temperature coefficient is determined by observing the shift of resonant frequency at a fixed setting of the meter while the temperature is changed. Changes in cavity are monitored by a thermocouple junction attached to the meter. The $Q$ of the cavity is determined by observing the half-power points on the response curve of the cavity for a signal which is frequency modulated through the resonance frequency.

## Detection of Microwave Signals

Because the power of the harmonics used as standard-frequency signals is often as low as 1 microwatt, direct detection by means of a crystal diode and a sensitive current meter is usually impractical. In addition, the useful power at the detector is further reduced by a nominal insertion loss of 10 db for the transmission filter and 10 db each for the padding attenuators. The power available at the detector is then about 0.001 microwatt. Therefore, when a frequency meter with a built-in crystal detector is to be calibrated, a higher power CW oscillator is used and adjusted to the frequency of the standard signal. Amplification of the beat note between the standard signal and a small portion of the oscillator output is sufficiently high to permit the adjustment of the oscillator to the same frequency as the standard-frequency signal. The accompanying



**Harmonic generators used in the NBS microwave frequency standard provide frequencies from 300 Mc (top left) to 75,000 Mc (right, second from bottom). The unit in the lower right corner is a frequency doubler for the range between 26,000 and 40,000 Mc.**

precision is decreased approximately one order of magnitude. The remainder of the oscillator power is sufficient to permit the crystal current from the detector to be monitored with a microammeter.

When the type of calibration is such that the standard-frequency signal can be passed through the meter to be calibrated, a sensitive receiver is used to detect the signal. In the frequency range 300 to 750 Mc a double superheterodyne panoramic receiver is employed; above 750 Mc a sensitive spectrum analyzer detects the signal.

Direct reading local oscillators of the external-cavity reflex klystron type generate the signals from 750 to 11,000 Mc. Above 11,000 Mc, internal-cavity reflex klystrons, mounted directly on the waveguide connecting the meter to the standard, provide local oscillator power. Because the power of the local oscillator is much greater than that of the standard signal, the height of the pulse displayed is directly proportional to the power of the standard signal. The frequency meter being calibrated is tuned to resonance by observing the relative pulse height on the cathode ray tube of the analyzer. Voltage gains of 160 db are possible with the spectrum analyzer, which can then detect microwave signals as low as 0.1 micro-microwatt.

The development work in progress at the National Bureau of Standards is aimed to improve the calibration techniques at frequencies above 40,000 Mc. Many of the components can be scaled down from the designs employed in lower frequency equipment, but the harmonic generators and crystal detectors normally used at the lower frequencies are about as small as manufacturing techniques will permit. Thus some other technique must be utilized in order to develop similar equipment for the higher microwaves. The engineering effort at the Bureau is concentrated on three major research projects for frequencies above 40,000 Mc: (1) crystal harmonic generators; (2) crystal detectors—mixer crystals in which the local oscillator power is adequate—and crystal video detectors, in which the local oscillator power is less than 1 milliwatt; and (3) development of secondary frequency standards.

A technique is now under investigation for mixing an interpolation oscillator signal with the outputs of the fixed microwave frequency standard to improve the continuous frequency coverage. Amplitude modulation of a standard-frequency signal in a magnetic attenuator offers certain possibilities. Because only small power levels are available at frequencies above 40,000 Mc, it is necessary that a passive secondary standard of frequency require very little power. A waveguide-contained interferometer design currently under consideration shows promise as a reliable secondary standard of frequency.

The future program of the NBS microwave frequency standards laboratory includes expansion of the calibration facilities to permit extension of the present 300-Mc to 75,000-Mc range upward to 100,000 Mc and higher. Attempts are being made to simplify high-precision frequency measurements by providing higher power in the standard signals at the microwave frequencies. Clocks using ammonia and oxygen, employing gas absorption techniques, are under development and promise accuracies equal to or better than those obtained by astronomical methods. Recent research has indicated that the ammonia clock as a standard is several orders of magnitude better than current secondary standards, and approximately equal to the precision of long-distance radio links to the WWV standard signals. Even greater absolute accuracies are possible from a standard based on atomic beam techniques, as in the NBS cesium clock.

*For further technical details, see* The microwave frequency standard, *by L. J. Rueger and A. E. Wilson, Radio and Television News* **49**, 3 (*March 1953*). *For details on atomic standards, see* Spectral lines as frequency standards, *by Harold Lyons, Annals N. Y. Acad. Sciences* **55**, 831 (*November 1952*).

*The fee schedule for NBS calibration of microwave frequency equipment is as follows: $33.00 to $42.00 for the first frequency calibration point, and $5.00 to $8.00 for each additional frequency calibration point depending on the type of secondary standard. More complete information may be obtained from the National Bureau of Standards, Washington 25, D. C.*

# X-Ray Diffraction Patterns

## *for Identification of Inorganic Solids*

CHEMICAL COMPOUNDS can be positively identified by X-ray diffraction measurements of their characteristic interplanar spacings. Because each chemical compound produces a distinctive X-ray pattern, showing its unique chemical composition and structure, the technique of X-ray diffraction is being increasingly utilized by scientists for the nondestructive analysis and identification of materials.

The technique of X-ray diffraction is a useful tool in the laboratories of metallurgical, oil, electronics, building, and pharmaceutical industries but more especially in the chemical industry. Heavy chemicals, ceramics, explosives, pigments, dyes, plastics, synthetic fibers, and many more substances are studied, inspected, and controlled, both as raw materials and in finished form, by the analysis of their X-ray diffraction patterns.

The regular arrangement of component atoms is a characteristic property of a crystalline material. Since the wavelength of X-rays is of the same order of magnitude as the interatomic spacing in crystals, these rays, when directed through such substances, are diffracted by the crystals, which act as a three-dimensional diffraction grating. For any particular crystalline species the intensities of the diffraction maxima and the angles at which they occur provide a unique pattern and hence a useful and positive means of identification. This method of identification of crystalline substances (and most solids except glasses are crystalline in some degree) has certain definite advantages over ordinary chemical anlysis. As the results are obtained directly in terms of compounds rather than of elements, X-ray diffraction patterns indicate the particular crystal form of a compound and, in the case of mixtures, give the form of each compound present.

Improvements in equipment and techniques are contributing to increased accuracy of X-ray diffraction data. The use of the Geiger counter for detecting X-ray diffraction effects has made more accurate measurement of interplanar spacings possible.

The usefulness of X-rays in the laboratory for chemical analysis increases in proportion with the growth and effectiveness of the expanding card index upon which it is more or less dependent. Accurate X-ray diffraction data, recorded in terms of interplanar spacings in angstrom units and relative intensities of the diffraction lines, must therefore be available for the widest possible number of substances. The Joint Committee for chemical analysis by X-ray diffraction methods, representing a large portion of X-ray crystallographers in industry, universities, and government research laboratories, and sponsored by the American Crystallographic Association, the American Society for Testing Materials, and the British Institute of Physics, has published a card file of these data, which over a period of several years has grown to more than 4,000 compounds. However, there has been much duplication; and some misleading patterns have resulted, particularly from use of older, less accurate data. This Committee through the National Bureau of Standards is stimulating a program of general improvement of the X-ray file, and has provided a research fellowship at NBS to this end. Thus far the direction of effort has been to eliminate duplicated patterns that exist in the X-ray file.

Two volumes of data have been published by the National Bureau of Standards and a third is in press. The two published volumes present patterns made recently at NBS for 84 inorganic substances, compare them with those that were to be found in the ASTM file and in the literature and recommend them for adoption as standard patterns. Five patterns, for selenium dioxide, zinc borate, magnesium tungstate, alpha-tin, and uranium dioxide, were not represented in the ASTM file but are compared with other patterns in the literature. The NBS powder patterns were made from samples of high purity, checked by spectrographic analysis. Miller indices were assigned to the *d*-spacings of each pattern using known crystal-structure considerations. Lattice constants calculated from the NBS data are compared with values from the literature. The density was calculated for each material; and, wherever possible, the refractive indices were measured.

Volume I includes recommended patterns for Mg, Al, Ni, Cu, Zn, Ge, Mo, Pd, Ag, Sn, Te, W, Ta, Pt, Au, Pb, BeO, MgO, $SiO_2$ (low cristobalite), $SiO_2$ (high cristobalite), CaO, $TiO_2$ (rutile), $TiO_2$ (anatase), NiO, CuO, $GeO_2$, $As_2O_3$, $SeO_2$, $SnO_2$, $CeO_2$, $ThO_2$, $Ca(OH)_2$, $NH_4Cl$, LiF, LiCl, NaF, KF, KCl, KBr, KI, $CaF_2$, $BaF_2$, $Hg_2Cl_2$, $HgCl_2$, $HgI_2$, PbFCl, KCN, NaCN (cubic), NaCN (orthorhombic), $Sr(NO_3)_2$, $Ba(NO_3)_2$, $ZnB_2O_4$, $Mg_2SiO_4$, and $MgWO_4$. Volume II contains data for C (diamond), Si, Ga, Zr, $\alpha$–Sn, Re, ZnS (wurtzite), ZnS (sphalerite), PbS (galena), $\alpha$–$Al_2O_3$ (corundum), $Cu_2O$ (cuprite), ZnO (zincite), CdO, $Tl_2O_3$, PbO (litharge), PbO (massicot), $UO_2$, $MgAl_2O_4$ (spinel), $ZnAl_2O_4$, NaCl (halite), CsCl, $PbCl_2$ (cotunnite), $PbBr_2$, $NH_4Br$, $CaCO_3$ (calcite), $BaCO_3$ (witherite), $PbCo_3$ (cerussite), $Na_2SO_4$ (thenardite), $SrSO_4$ (celestite), and $Zn_4(OH)_2Si_2O_7.H_2O$ (hemimorphite).

The review and improvement of duplicated data in the X-ray diffraction card file will be more than one half completed with publication of the first three volumes. Another phase of the program is devoted to the addition of new data to the file, which comprise only a small percentage of the work already completed. As this work progresses other volumes will be published in the series.

*See* Standard X-ray Diffraction Powder Patterns, *NBS Circular 539, Volume I by Howard E. Swanson and Eleanor Tatge, 95 pages, 45 cents; and Circular 539, Volume II by Howard E. Swanson and Ruth K. Fuyat, 65 pages, 45 cents. (Order from Government Printing Office, Washington 25, D. C.)*

# Index to Technical News Bulletin—Volume 37, 1953


A, B

Page

Accelerometers, barium titanate, symposium (Aug.) 125
Acoustic materials (installed), sound absorption (Apr.) 54
Adaptable electronic chassis (Oct.) 159
Aircraft, fuel handling accessories (Mar.) 33
Analog computer, resistance network (Feb.) 19
Analytical balance, recording (June) 86
Angular standard, precise (Aug.) 118
Asbestos, reclamation (Sept.) 139
Automotive combustion, new data (Aug.) 113
Balance, recording analytical (June) 86
Barium titanate accelerometers, symposium (Aug.) 125
Basic instrumentation at NBS (Sept.) 129
Bone char research, technical session, 1953 (May) 69
Building floors, live loads (Jan.) 13
Butyl-impregnated leather (Mar.) 44

C

Calibrator for vibration pickups (Dec.) 181
Calibrator, vibration, resonance-type (May) 78
Cellular electronic construction (June) 83
Cement, silicate, mixing (motion picture) (Apr.) 53
Cements, magnesite, heat generation in hardening (Apr.) 62
Charts, test, for photographers (Aug.) 115
Chassis, adaptable electronic (Oct.) 159
Circuity "packages" for electronic computers (Mar.) 36
Code for protection against lightning (handbook) (May) 77
Combustion, automotive, new data (Aug.) 113
Compton spectrometer, NBS magnetic (Jan.) 1
Computer, National Bureau of Standards Western Automatic, recent developments and operating experience (Oct.) 145
Computer, resistance network analog (Feb.) 19
Computers, electronic (high speed), diode-capacitor memory (Nov.) 171
Computers, electronic circuitry "packages" (Mar.) 36
Concrete floors, fire resistance (Feb.) 29
Concrete, impact resistance (Mar.) 45
Conference on high-frequency measurements (third) (Mar.) 38
Conference on Weights and Measures, thirty-eighth national (Aug.) 126
Constantan (iron-) thermocouple tables (Dec.) 182
Copper, tensile properties (Apr.) 52
Corrosion of galvanized steel underground (May) 76
Corrosion of low-alloy irons and steels in soils (Oct.) 151
Corrosion rate, electrical measurement (Feb.) 22
Cracking of masonry (Mar.) 40
Cryogenic engineering laboratory, NBS–AEC (Oct.) 152
Crystals, metal, orientation determined with polarized light (Mar.) 46

D, E

Deviation meter, frequency (July) 107
Diffraction patterns, X-ray 189
Dielectric properties of pure substances (Oct.) 158
Diode-capacitor memory for high-speed electronic computers (Nov.) 171
Dyes, phototropic (Apr.) 56
Effects of tannage on the properties of leather (Jan.) 6
Electrical measurement of corrosion rate (Feb.) 22
Electron-beam interferometer (July) 101
Electron tubes, vibration generator (July) 108
Electronic chassis, adaptable (Oct.) 159
Electronic computers, circuitry "packages" (Mar.) 36
Electronic construction, cellular (June) 83
Electronic flowmeter (Feb.) 30
Electronic flowmeter—Correction (Sept.) 142
Electronics, modular design and mechanized production, Project Tinkertoy (Nov.) 161
Electrons, film dosimetry (Jan.) 3

F

Failures in welded ships (Feb.) 24
Film dosimetry of electrons (Jan.) 3
Fire resistance of concrete floors (Feb.) 29
Firebrick, permeability (July) 110
Flexer for leather (Dec.) 179
Floors (building), live loads (Jan.) 13
Floors, concrete, fire resistance (Feb.) 29
Flowmeter, electronic (Feb.) 30
Flowmeter, electronic—Correction (Sept.) 142
Focus and quality determination of searchlight reflections (June) 93
Frequency deviation meter (July) 107
Frequency standard, microwave (Dec.) 184
Frequency standard (NBS primary), improvements (Jan.) 8
Fuel handling accessories for aircraft (Mar.) 33

G, H

Galvanized steel, underground corrosion (May) 76
Gases, viscosimetry at high temperatures and pressures (Apr.) 49
Glass heating panels (radiant) (May) 65
Goniometer, versatile photometric (Sept.) 133
Half life of polonium (Feb.) 23
Heat-capacity standards (Jan.) 15
Heat generation in the hardening of magnesite cements (Apr.) 62
Heating panels, radiant glass (May) 65
High-capacity load calibrating devices (Sept.) 136
High-frequency measurements, third conference (Mar.) 38
High-pressure pneumatics (July) 104
High-resolution micromanometer (Sept.) 140

I

Page

Impact resistance of concrete (Mar.) 45
Improved meteorological soundings (June) 81
Improved refractometer (Aug.) 135
Improvements in the NBS primary standard of frequency (Jan.) 8
Institute for numerical analysis (July) 97
Instrumentation, basic, at NBS (Sept.) 129
Instrumentation conference (June) 84
Insulators, porcelain, lightning resistance (Sept.) 142
Interferometer, electron beam (July) 101
Interferometer measurement of corrosion (June) 88
Intermetallic compounds, semiconducting (Nov.) 174
Invar surveying tapes, thermal expansion (Aug.) 124
Ionosphere recorder, low-frequency (Apr.) 60
Iron-constantan thermocouple tables (Dec.) 182

L, M

Leather, butyl-impregnated (Mar.) 44
Leather, effects of tannage on properties (Jan.) 6
Leather flexer (Dec.) 179
Lightning protection code (handbook) (May) 77
Lightning resistance of porcelain insulators (Sept.) 142
Live loads on building floors (Jan.) 13
Load calibrating devices, high capacity (Sept.) 136
Low-frequency ionosphere recorder (Apr.) 60
Magnesite cements, heat generation in hardening (Apr.) 62
Magnetic Compton spectrometer (Jan.) 1
Magnetizer, simple (June) 95
Masonry cracking (Mar.) 40
MDE-Modular design of electronics, Project Tinkertoy (Nov.) 161
Memory (diode-capacitor) for high-speed electronic computers (Nov.) 171
Metal crystals, orientation determined with polarized light (Mar.) 46
Meteorological soundings, improved (June) 81
Meter, frequency deviation (July) 107
Micromanometer, high-resolution (Sept.) 140
Microwave frequency standard (Dec.) 184
Military X-ray equipment, field (May) 72
Mixing silicate cement (motion picture) (Apr.) 53
MPE-Mechanized production of electronics, Project Tinkertoy (Nov.) 161
Multimegohm resistors, measurement (June) 90

N, O

NBS-AEC cryogenic engineering laboratory (Oct.) 152
New data on automotive combustion (Aug.) 113
Numerical analysis, institute (July) 97
Obstacle-gain VHF transmission (Dec.) 177
Ordnance development facilities (Aug.) 120
Orientation of metal crystals determined with polarized light (Mar.) 46
Oscillator, precision transistor (Feb.) 17
Osmometer, simple, rugged (May) 68

P

Permeability of firebrick (July) 110
Petroleum measurement tables, standard (May) 79
Petroleum measurement tables, standard (Aug.) 123
Phonograph-needle drag distortion (Mar.) 42
Photometric goniometer, versatile (Sept.) 133
Phototropic dyes (Apr.) 56
Pickup (vibration) calibrator (Dec.) 181
Pneumatics, high-pressure (July) 104
Polarized light for determining orientation of metal crystals (Mar.) 46
Polonium, half life (Feb.) 23
Porcelain insulators, lightning resistance (Sept.) 142
Precise angular standard (Aug.) 118
Project Tinkertoy, a modular design of electronics and mechanized production of electronics (Nov.) 161
Protection against lightning, code (handbook) (May) 77
Pure substances, dielectric properties (Oct.) 158

Q, R

Quality and focus determination of searchlight reflections (June) 93
Radiant glass heating panels (May) 65
Radiation handbook (Apr.) 55
Reclamation of asbestos (Sept.) 139
Recording analytical balance (June) 86
Refractometer, improved (Sept.) 135
Resistance network analog computer (Feb.) 19
Resistors, multimegohm, measurement (June) 90
Resolution test charts for photographers (Aug.) 115
Resonance-type vibration calibrator (May) 78

S

Searchlight reflections, focus and quality determinations (June) 93
Semiconducting intermetallic compounds (Nov.) 174
Sensitive corrosion measurements with an interferometer (June) 88
Ship failures, welded (Feb.) 24
Soil corrosion of low-alloy irons and steels (Oct.) 151
Sound absorption of installed acoustic materials (Apr.) 54
Spectrometer, NBS magnetic Compton (Jan.) 1
Spectrophotometric standard for the ultraviolet (Jan.) 7
Standard of frequency (NBS primary), improvements (Jan.) 8
Standard petroleum measurement tables (May) 79
Standard petroleum measurement tables (Aug.) 123
Standards, heat-capacity (Jan.) 15
Steel, galvanized, underground corrosion (May) 76
Surveying tapes (invar) thermal expansion (Aug.) 124
SWAC, National Bureau of Standards Western Automatic Computer, recent developments and operating experience (Oct.) 145
Symposium on barium titanate accelerometers (Aug.) 125

T, U

| | Page |
|---|---|
| Tannage, effect on properties of leather (Jan.) | 6 |
| Tapes, surveying (invar), thermal expansion (Aug.) | 124 |
| Teflon, transitions (May) | 70 |
| Tensile properties of copper (Apr.) | 52 |
| Test charts for amateur photographers (Aug.) | 115 |
| Thermal expansion of invar surveying tapes (Aug.) | 124 |
| Thermocouple tables, iron-constantan (Dec.) | 182 |
| Tooth structure, X-ray scattering study (June) | 85 |
| Transistor oscillator, precision (Feb.) | 17 |
| Transitions in Teflon (May) | 70 |
| Tubes, electron, vibration generator (July) | 108 |
| Ultraviolet, spectrophotometric standard (Jan.) | 7 |
| Underground corrosion of galvanized steel (May) | 76 |

V, W, X

| | Page |
|---|---|
| Versatile photometric goniometer (Sept.) | 133 |
| VHF transmission, obstacle-gain (Dec.) | 177 |
| Vibration calibrator, resonance-type (May) | 78 |
| Vibration generator for electron tubes (July) | 108 |
| Vibration pickup calibrator (Dec.) | 181 |
| Viscosimetry of gases at high temperatures and pressures (Apr.) | 49 |
| Viscosity standard adopted (July) | 100 |
| Weights and measures conference, thirty-eighth national (Aug.) | 126 |
| Welded ship failures (Feb.) | 24 |
| X-ray diffraction patterns | 189 |
| X-ray equipment, military, field (May) | 72 |
| X-ray scattering study of tooth structure (June) | 85 |

# Publications of the National Bureau of Standards

## Periodicals

Journal of Research of the National Bureau of Standards, volume **51**, number 5, November 1953 (RP2453 to RP2457 incl.). Annual subscription $5.50.

Technical News Bulletin, volume **37**, number 11, November 1953, 10 cents. Annual subscription $1.00.

CRPL–D111. Basic Radio Propagation Predictions for February 1954. Three months in advance. Issued November 1953. 10 cents. Annual subscription $1.00.

## Research Papers

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RP2454. A radio-frequency permeameter. Peter H. Haas.

RP2455. On mildly nonlinear partial difference equations of elliptic type. Lipman Bers.

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# TECHNICAL NEWS BULLETIN

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## Contents

| | Page |
|---|---|
| Obstacle-gain VHF transmission | 177 |
| NBS leather flexer | 179 |
| Vibration pickup calibrator | 181 |
| Iron-constantan thermocouple tables | 182 |
| NBS microwave frequency standard | 184 |
| X-ray diffraction patterns for identification of inorganic solids | 189 |
| Index, volume 37 | 190 |
| NBS publications | 191 |

## NBS Publications (*continued*)

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